COMMENT ON RECENT TUNNELING MEASUREMENTS ON $Bi_2Sr_2CaCu_2O_8$

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Recent PCT and STM measurements of the tunneling conductance on $Bi_2Sr_2CaCu_2O_8$ (Bi-2212) [1] [2] with various hole doping reveal an interesting asymmetry in the conductance peaks. In all cases, the negative bias peak is higher than the positive bias peak. The purpose of this comment is to point out the potential significance of this type of conductance peak asymmetry in determining the symmetry of the underlying superconducting order parameter.

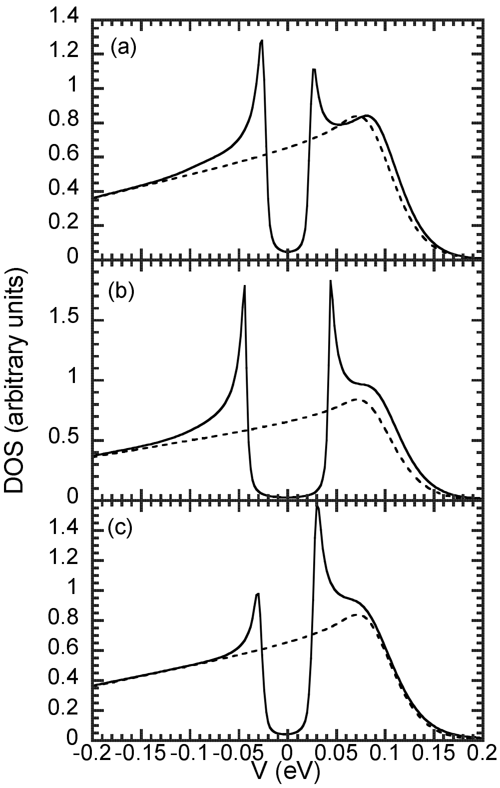

FIG. 1. Tunneling DOS for (a) $d_{x^2-y^2}$ gap, (b) s-wave gap, and (c) $s_{x^2+y^2}$ gap. All DOS were obtained using $\Delta_o = 0.043$ eV, $\gamma = 0.002$ eV, $\theta = 0.25$ rad, $\theta_o = 0.05$ rad. c_o in the band structure has been modified to 0.2 eV to minimize the influence of the upper band edge. The dashed lines correspond to the normal state. Refer to Ref. 3 for definitions of the parameters.

A calculation by the present authors [3] of the tunneling density of states (DOS) for $d_{x^2-y^2}$ superconductors incorporating group velocity, tunneling directionality, and a realistic band structure extracted from ARPES indicates that such peak asymmetry seen in tunneling experiments may be an intrinsic property of $d_{x^2-y^2}$ pairing.

In this comment, we explore this issue further by comparing calculations of the tunneling DOS for $d_{x^2-y^2}$ ($\Delta(\mathbf{k}) = \Delta_o[\cos(k_x a) - \cos(k_y a)]/2$), isotropic s-wave ($\Delta = \Delta_o$), and $s_{x^2+y^2}$ ($\Delta(\mathbf{k}) = \Delta_o[\cos(k_x a) + \cos(k_y a)]$) gap symmetries. Figure 1 displays typical results for the three gap symmetries. Figure 1(a) for the $d_{x^2-y^2}$ state illustrates that the negative energy peak is higher than the positive energy peak, whereas in Fig. 1(c), the opposite is the case for the $s_{x^2+y^2}$ symmetry. This peak asymmetry remains the same with variations in chemical potential and tunneling direction in the model and appears to be an intrinsic and robust property of directional tunneling into a $d_{x^2-y^2}$ or $s_{x^2+y^2}$ state. Negative values of V in Fig. 1 correspond to electron extraction from the superconductor while positive values of V correspond to electron injection into the superconductor. This sign convention is the same as in the experiments. [1] [2] The isotropic s-wave DOS (Fig. 1(b)) shows approximately symmetric peaks, with the slight asymmetry here tending to reflect the shape of the underlying normal state DOS. These results suggest that the peak asymmetry in the recent optimal Bi-2212 data [1] [2] may be a subtle signature of a $d_{x^2-y^2}$ gap.

Theoretical studies of high-T_c superconductors indicate that a change in symmetry, from $d_{x^2-y^2}$ to $s_{x^2+y^2}$, may occur in the overdoped region of the phase diagram. [4] Figure 1 illustrates that such a change in the symmetry would be accompanied by a switching of the asymmetry of the conductance peaks in tunneling conductance measurements. However, the most likely example of cuprate oxide s-wave superconductivity appears to be the electron doped NdCeCuO [5] which makes it tempting to speculate that one might anticipate a change in gap symmetry from $d_{x^2-y^2}$ to $s_{x^2+y^2}$ to occur towards the underdoped region of the phase diagram instead.

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